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Transverse Cracking Distress and Vertical Dynamic Impact Load From Heavy Truck Axles - A Feasibility Study

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Transverse Cracking Distress and Vertical Dynamic Impact Load From Heavy Truck Axles - A Feasibility Study

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Abstract:	Transverse cracks, if left untreated, will develop into more drastic distresses such as multiple cracking, spalling and potholes, deformation, and even structural failure. These distresses are irreversible and are a major factor in pavement surface roughness. The Ministry of Transportation of Ontario had, from a previous research project, a Dynamic Tire Force Trailer capable of measuring tire/pavement forces along the vertical, longitudinal and lateral axes. This capability combined with the ability to apply various vertical loads, measure distance from a reference point and operate at highway speeds, provided an unique opportunity to investigate dynamic pavement impact loads from heavy truck axles. This presentation gives the results of a feasibility study using this Dynamic Tire Force Trailer, to develop a relationship between the vertical dynamic impact loads and the transverse cracks which generated these loads. Such a relationship will enable our Ministry to establish a threshold criteria to aid our pavement designers in the maintenance and rehabilitation design decisioning process. Results from a series of test runs on Highway 401 in Southern Ontario show that it is possible to correlate heavy axle vertical acceleration and transverse crack deformation. It is recommended that a full scale study be conducted to establish an evaluation methodology for transverse crack distress based on the above relationshiip.
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1/ Introduction

Transverse cracking, if left untreated, will develop into more drastic distresses such as multiple cracking, spalling and potholes, deformation, and even structural failure. These distresses are irreversible and are a major factor in pavement surface roughness. The most undesirable distress characteristic of a transverse crack is the permanent deformation commonly known as cupping. Cupping is described as a depression of the pavement profile at the transverse crack.

On-going investigation shows that transverse crack cupping is caused by internal deterioration which usually takes place at the bottom of the asphalt layers and progresses upward [1] [2]. In the case of a heavily travelled highway, this internal deterioration can result in half or more of the original asphalt layers disintegrating into loosely bonded materials from the bottom upward, resulting in a depression at and about the transverse crack.

This condition has become of particular concern to the pavement designer because it is costly to redress under the rehabilitation programme. An added problem is determining the internal nature of the distress. The pavement designer, short of doing an expensive coring investigation programme, must rely on subjective judgement to recommend a viable maintenance or rehabilitation design decision.

The Transportation Technology and Energy Branch had, from a previous research project, a Dynamic Tire Force Trailer capable of measuring tire/pavement forces along the vertical, longitudinal and lateral axes. This capability combined with the ability to apply various vertical loads, measure distance from a reference point and operate at highway speeds, provided a unique opportunity to investigate dynamic pavement impact loads from heavy truck axles and their relationship to pavement surface roughness. [3]

In late November 1988, the Pavements and Roadway Office, the Vehicle Technology Office and the Regional Geotechnical Office jointly made a preliminary trial of the above unit in the South Western Region. Trial results from sites on Highways 401 and 73 selected by the region indicated that there was a very good possibility of utilizing this tire/pavement interaction data to develop a relationship between the measured vertical dynamic impact load and the transverse crack which generated this load.

In December 1988, the Pavements and Roadway Office with the cooperation of the other two Offices, initiated and carried out a feasibility study to ascertain whether the following objectives were attainable:

1. Develop a severity assessment scale for cupping distress of the transverse crack based on the vertical dynamic impact load from heavy axles.
2. Develop threshold criteria for maintenance and rehabilitation using this tire/pavement interaction data.
3. Develop functional equipment for routine operational usage.

The potential benefits are:

1. Development of new techniques and equipment for pavement performance evaluation.
2. Development of data for heavy vehicle performances and the relationship with pavement surface roughness.
3. Possibility of extending pavement service life through more cost-effective solutions.

2/ Experimental Site

The experimental site chosen by the Regional Geotechnical Office was located on the westbound lanes of Highway 401 between Tilbury and Windsor (Figure 1).

This pavement was built in 1952-1953 as a 225 mm (9 in.) plain non-reinforced concrete pavement, 6.1 m (20 ft) slab with no load transfer devices between slabs. The base design was 100 mm (4 in.) granular "A" over 125 mm (5 in.) granular "B" over a heavy clay subgrade.

In 1967, the badly stepped pavement was resurfaced with a thin lift of sand asphalt 20 mm (1 in.) under Contract #67-128.

Six years later in 1973, a major resurfacing Contract #73-171 was called with the following design: 50 mm (2 in.) modified HL5 levelling course, 40 mm (1.6 in.) HL5 base course, and 40 mm (1.6 in.) HL1 wearing course.

In 1981, after eight service years, a rout and seal maintenance contract was finally carried out after the Regional Geotechnical Office recommended that it should be done in order to retard the cupping process of the transverse cracks and consequently prolong the pavement service life.

In 1988 under Work Project No. 190-88-01 [4], this pavement was investigated and designated for rehabilitation in 1989 because of the severe cupping of the transverse cracks, both sealed and unsealed.

The control site chosen by the Regional Geotechnical Office was located on Highway 73, south of Highway 401 towards Aylmer, and provided a reference for axle responses to pavement surface irregularities.

This pavement was reconstructed in 1988 with completion in October 1988. Being brand new it has a very good smooth ride condition.

3/ Work Plan

The work plan and responsibilities of the individual participating Office, were:

Geotechnical Office, Southwestern Region

- selection of transverse cracks for experimental study, maximum number to be 10.
- subjective classification of severity for each of the selected transverse cracks.
- marking and identification of each selected crack.
- core investigation of each selected crack.
- provision of necessary traffic control.

Pavements and Roadway Office

- provision of longitudinal and transverse profiles of the selected transverse cracks with a laser level. Longitudinal profile on the left wheel path 3 meters each side of the transverse crack.
- Benkelman Beam deflection measurements at the selected cracks.
- Photographic record of the selected cracks.

Vehicle Technology Office

- preparation of the Dynamic Tire Force Trailer and the Benkelman Beam Test Vehicle for the study.
- running and recording all results from the Dynamic Tire Force Trailer on the experimental and control sites.
- recording of work procedures on video.
- analysis of the Dynamic Tire Force Trailer results.

The work plan was carried out on December 20 and 21, 1988 with 8 selected transverse cracks tested.

4/ Dynamic Tire Force Trailer

The test vehicle consisted of a tractor/semi-trailer, capable of applying controlled vertical axle loads to a belly mounted air-lift axle. This air-lift axle under a standard 13.7 meter (45 foot) flat-bed had a 3-axis truck wheel-force transducer mounted on its left end. A single truck tire was mounted, in the outboard position, on the transducer and another in a similar location on the opposite end of the axle. Ballast of approximately 6.7 tonnes (14,700 pounds) in the form of concrete blocks at the rear and 4.5 tonnes (1000 gallons) of water at the front, plus the weight of tanks, gasoline powered air compressor, and trailer body provided a substantial reaction frame for loading the air-lift axle. Air-lift axle controls and a visual monitor of the vertical load were located in the tractor.

The following signals were electrically conditioned and frequency multiplexed in the signal control cabinet, located on the trailer.

- left tire vertical load
- vehicle speed
- distance from the reference point
- axle vertical acceleration
- air bag pressure
- axle displacement from the frame
- crack marker photo pulse.

The conditioned signals along with date, time and voice comment were stored in a data tape recorder located in the tractor.

A typical test required the static axle load to be set while the vehicle was stationary using the pressure regulator and local load readout on the trailer. The axle was then raised and the vehicle accelerated to normal highway speed. Prior to running the test, reflective tape had been placed across the lane at specific crack locations. On approach to the first location, the air-lift axle was commanded down, the photocell on the axle activated, and the tape recorder started. As the axle passed over the reflective tape, a pulse from the photocell reset the distance counter to zero and started accumulating distance data. Each successive marker generated a pulse to identify the cracks of interest, and hence the distance relative to the first marker. At the end of the test section, the axle was lifted and the tape recorder stopped.

of interest, and hence the distance relative to the first marker. At the end of the test section, the axle was lifted and the tape recorder stopped.

Upon completion of the test, the data tapes were replayed through a series of frequency modulation discriminators into a personal computer data acquisition system. The data presented by the computer were continuous analog traces, calibrated and scaled in engineering units. From this display, portions of data pertaining to specific predefined pavement cracks, indicated by the photo pulses, were selected for transfer to Lotus 1-2-3* . In Lotus the data was corrected for zero offset, plotted against time and distance, and a summary table generated, which indicated maximum, minimum and average values over the selected location.

5/ Results

Results obtained for the experiment are either presented in tabulated form or in graphical format:

- The Benkelman Beam deflection measurements were made with a 7500 pound left wheel load to match that of the wheel load from the Dynamic Tire Force Trailer. The beam probe was placed on the upstream edge of the transverse crack for the first static deflection measurement, and then the beam probe was moved to the downstream edge of the transverse crack for the second static deflection measurement (Table 1).
- The left wheel path longitudinal profile and the transverse crack transverse profile were obtained with precision levelling. The resultant rut depth measurements at the transverse cracks are tabulated in Table 1. Representative profiles from Test Cracks No. 4, 7, and 9 are presented in graphic form (see Figures 2 to 4).
- The results from the subjective assessment of transverse crack severity are tabulated in Table 1.
- The core investigation results for representative Test Cracks No. 4, 7, and 9 are given in Figure 5.
- The vertical dynamic impact load data for these representative test cracks and the control site on Highway 73 are given in graphical form in Figures 6, 7, 8, and 9.
- The vertical dynamic impact loads data versus the corresponding transverse cracks' subjective distress assessments and core conditions are given in Table 2.

* Copyright Lotus Corporation

6/ Discussion of Results

The findings of this feasibility study are discussed with respect to the following:

- *Load Bearing Capacity and Cupped Transverse Cracks*

  The static load deflections obtained with the Benkelman Beam indicated that the pavement structure is adequate even at the severely cupped transverse cracks. The range of deflections is from 0.30 mm (0.012 inches) to 0.82 mm (0.032 inches) which are acceptable compared to the design standard of 1.27 mm (0.050 inches).

  This was anticipated because of the underlying strength of the base, in this case the original concrete pavement and granular layers.

- *Internal Deterioration and Cupped Transverse Cracks*

  The core investigation results (Figure 5) and the measured longitudinal profiles of the cupped transverse cracks related quite well. Where there is no deterioration in the asphaltic layers, cupping is only slight or nonexistent . On the other hand, if the asphaltic layers had deteriorated drastically (Figure 5), the cupping was observed to be moderate to severe.

- *Vertical Dynamic Impact Load and Cupped Transverse Cracks*

  Inspection of graphs Figure 6, crack 4, (slight); Figure 7, crack 7 (moderate); Figure 8, crack 9 (severe); Figure 9 (smooth road) and Table 2, show that there were distinct differences between slight and severe cracks (cupping). Those described as slight by the core and visual survey, exhibited an initial negative or downward acceleration of approximately -1.0 *g* followed by a positive or upward acceleration of up to 1.6 *g*. Moderate cracks had slightly larger downward values and positive accelerations of up to 1.9 *g*. Severe to very severe had upward values between 2.0 and 4.0 *g* respectively. Smooth road conditions had values between +/- 0.5 *g*. In all cases cupping was characterized by a negative followed by a positive axle acceleration.

  Nominal single tire loads of 3.10 tones (6840 lbs) tended to decrease by 0.2 to 0.9 tonnes (450 to 2000 lbs) for slight to severe cracks respectively and then overshoot by 0.3 tonnes (660 lbs). The overshoot tended to be constant regardless of the severity of the cupping, whereas the decrease in measured tire load followed the increase in severity. This rather

unexpected result was perhaps due to a smoothing effect created by the tire footprint spreading the load as the tire rolled up and over the downstream edge of the cup.

Axle displacement from the trailer frame was also recorded although not presented. As expected it showed a smoothed version of the cup, with little correlation to the actual cup depression. All that could be noticed was that severe cracks had larger indicated depressions than those that were labeled as slight.

Crack location as determined by the test vehicle was measured with respect to a reflective marker placed in the middle of the lane on top of crack 2. According to survey data, crack 10 was located 4.228 km west of crack 2. Distance scale factors were generated from the first pass over the test section and used to determine locations on the second pass. These measurements indicated that the reflective marks on the selected cracks could be defined to within +/- 2 metres in the 4.2 km test section. Two locations did appear to be in error. Crack 3 should have been 622 metres from crack 2 but was indicated as only 500 metres. We believe this to be an error in survey data provided since all other locations checked to within the +/- 2 metres. Crack 8 appeared to be off by 6 metres but the survey information on the location was questionable.

From the data gathered during this preliminary test, it would appear that axle vertical acceleration may be the best indicator of the severity of cupping. A threshold set at +2.0 *g* would separate the slight to moderate cracks from the severe.

7/ Summary

The feasibility study results point toward the following:

1. Static load deflection from the Benkelman Beam is not a good indicator of internal deterioration for cupped transverse cracking.

2. It is possible to correlate the axle vertical acceleration responses in *g* generated by various degrees of cupping deformation at the transverse cracks.

3. It is possible to correlate the axle vertical acceleration responses in *g* generated by the transverse cracks and the internal deterioration of the same transverse cracks.

4. It is possible to correlate the degree of cupping deformation of the transverse cracks and their corresponding internal deterioration.

5. It is possible to establish a threshold criteria based on the vertical dynamic impact load responses in *g* for corrective and preventative maintenance, and rehabilitation design decisioning processes.

6. It is possible to develop innovative equipment with which better information becomes available for cost-effective maintenance, rehabilitation, and management of resources.

8/ Recommendations

It is recommended that a full scale study should be conducted with the following objectives:

1. Establish an evaluation methodology for transverse cracks based on the relationship between transverse crack distress and the vertical dynamic impact load from heavy axles.

2. Establish threshold criteria for maintenance, and rehabilitation using the established assessment methodology.

3. Develop and build a prototype equipment for high speed data collection as a routine operation.

4. Consider other equipment and methodology such as radar waveform assessment of internal deterioration of transverse cracks.

9/ References

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Table 1/ Transverse Crack Investigation HWY 401 Belle River to Puce
(Rut Depth Static Load Deflection Distress Evaluation)

Crack Number	Rut Depth (mm)			Benkelman Beam Deflection (mm)		Distress Evaluation							
						Severity of Cupping					Core Condition (Deterioration)		
	LEFT WHEEL PATH	RIGHT WHEEL PATH	SLOPE %	CRACK UPSTREAM	CRACK DOWN-STREAM	VERY SLIGHT	SLIGHT	MOD	SEVERE	VERY SEVERE	NONE	LESS THAN 20 MM	GREATER THAN 20 MM
2	8.9	8.6	2.2	0.30	0.60			X					X
3	9.1	10.4	1.7	0.60	0.82				X				X
4	15.0	4.8	2.0	0.60	0.40		X				X		
6	15.3	14.4	1.6	0.60	0.72				X				X
7	1.6	9.9	1.7	0.50	0.72			X					X
8	5.0	6.7	2.2	0.50	0.40	X					X		
9	5.3	16.0	1.7	0.50	0.72					X			X
10	5.7	5.0	2.2	0.30	0.40		X				X		

Table 2/ Transverse Crack Investigation HWY 401 Belle River to Puce
(Vertical Dynamic Load Vertical Acceleration in g)

Crack Number	Tire Load (tonnes)			Vertical Acceleration (g)		Distress Evaluation							
						Severity of Cupping					Core Condition (Deterioration)		
	MIN	AVG	MAX	MIN	MAX	VERY SLIGHT	SLIGHT	MOD	SEVERE	VERY SEVERE	NONE	LESS THAN 20 mm	GREATER THAN 20 mm
2	2.69	3.17	3.45	-1.13	+1.88			X					X
3	2.64	3.14	3.46	-1.35	+1.99				X				X
4	2.64	3.15	3.37	-1.03	+1.59		X				X		
6	2.25	3.07	3.43	-1.63	+2.32				X				X
7	2.50	2.93	3.48	-1.27	+1.86			X					X
8	2.83	3.15	3.35	-0.60	+1.14	X					X		
9	2.22	3.12	3.42	-1.78	+3.99					X			X
10	2.93	3.09	3.25	-0.44	+0.24		X				X		
HWY 73	2.02	2.39	2.76	-0.52	+0.42	New Pavement — No Cracks							

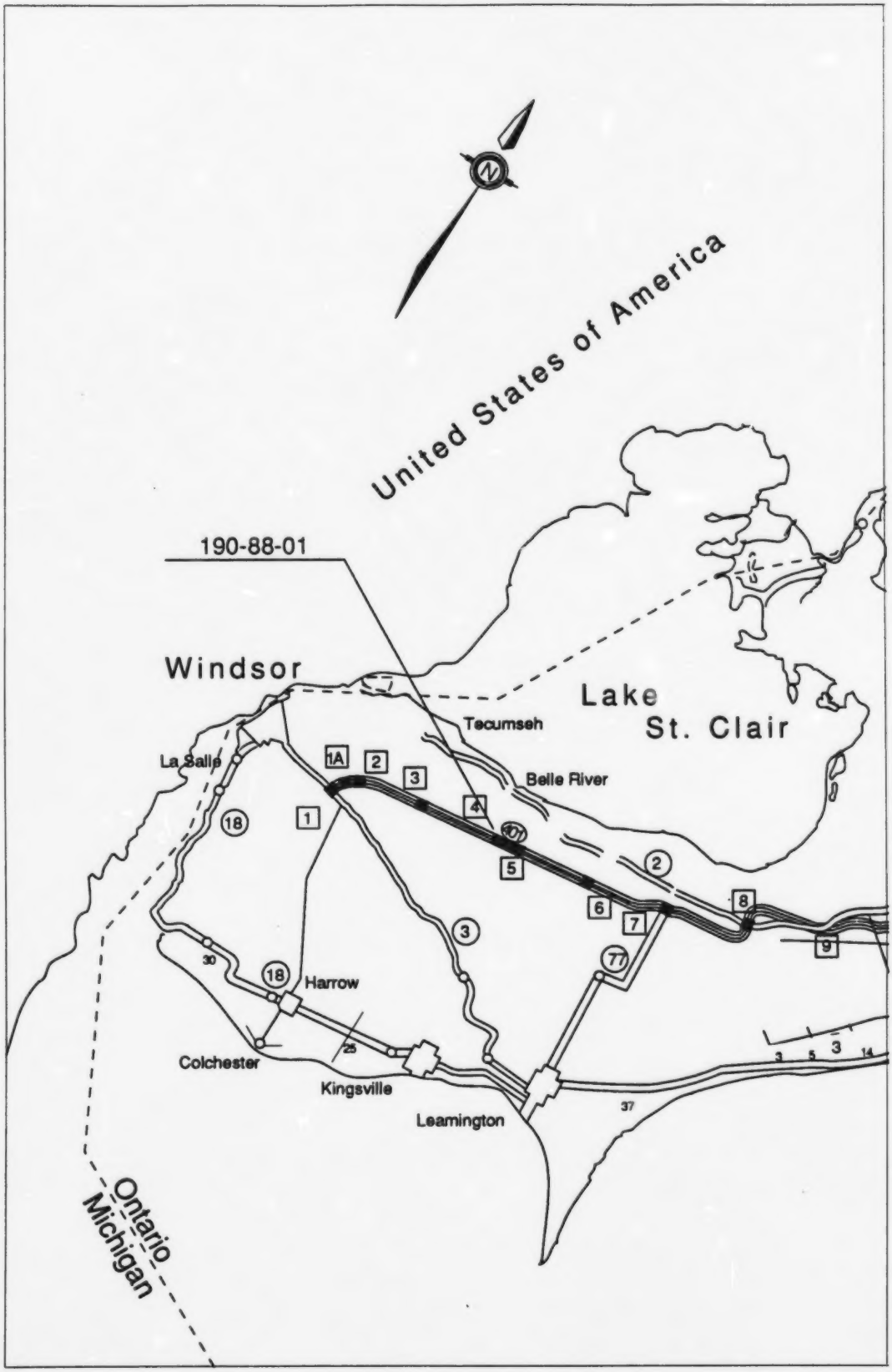


Figure 1/ Experimental Site on Highway 401

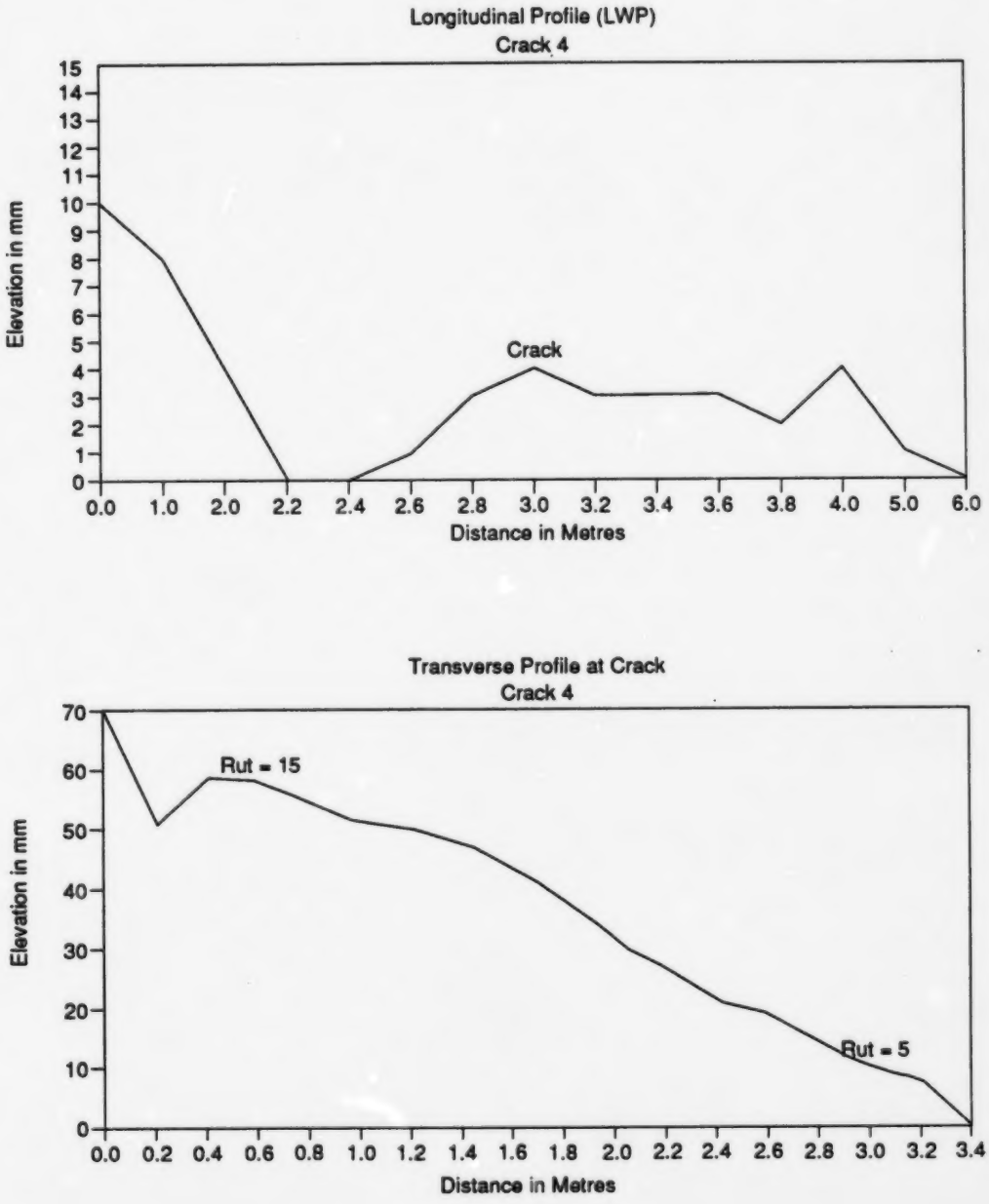
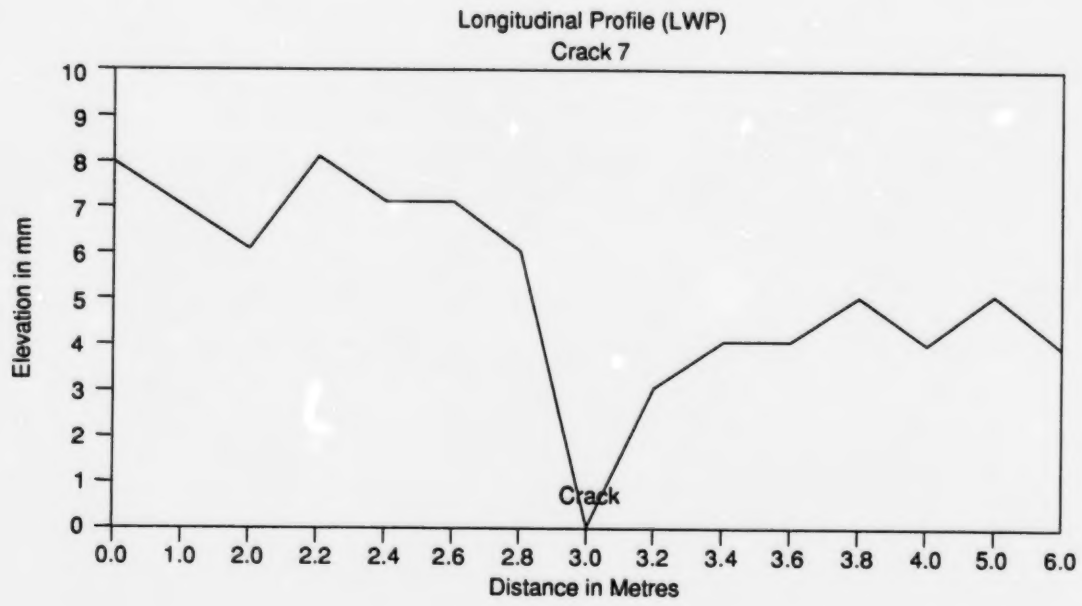


Figure 2/ Profiles of Test Crack No.4 (Rating: Slight)



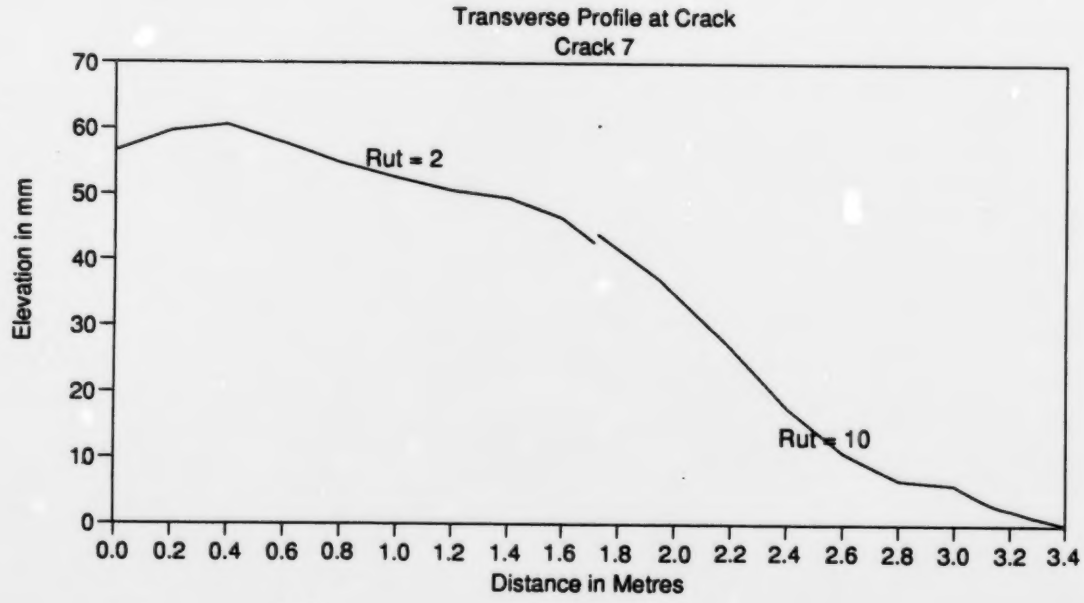
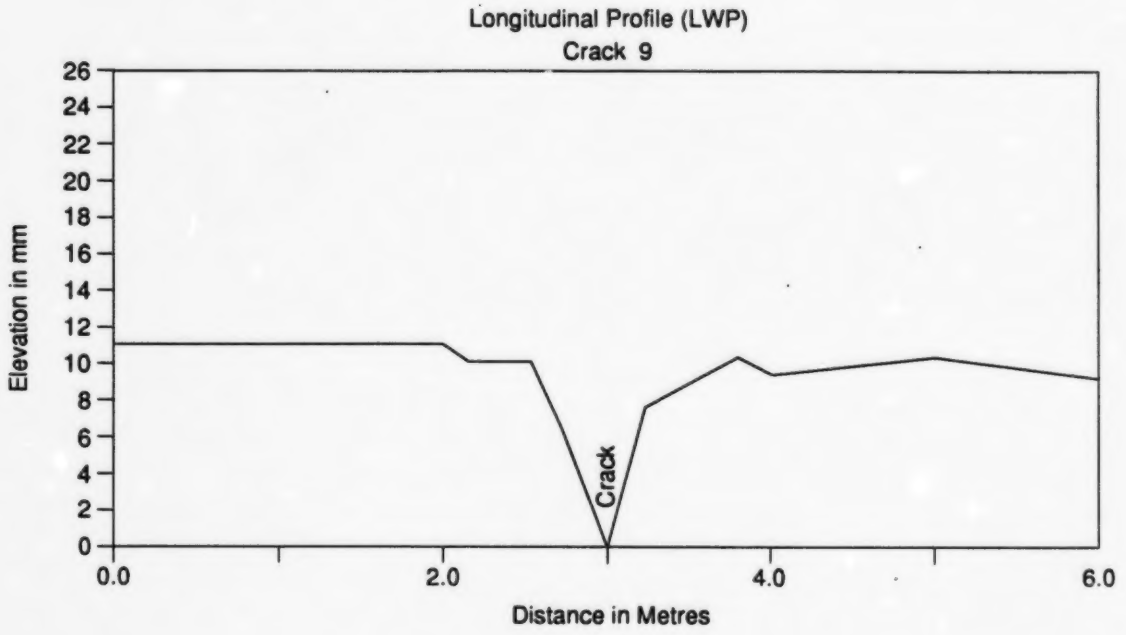


Figure 3/ Profiles of Test Crack No.7 (Rating: Moderate)



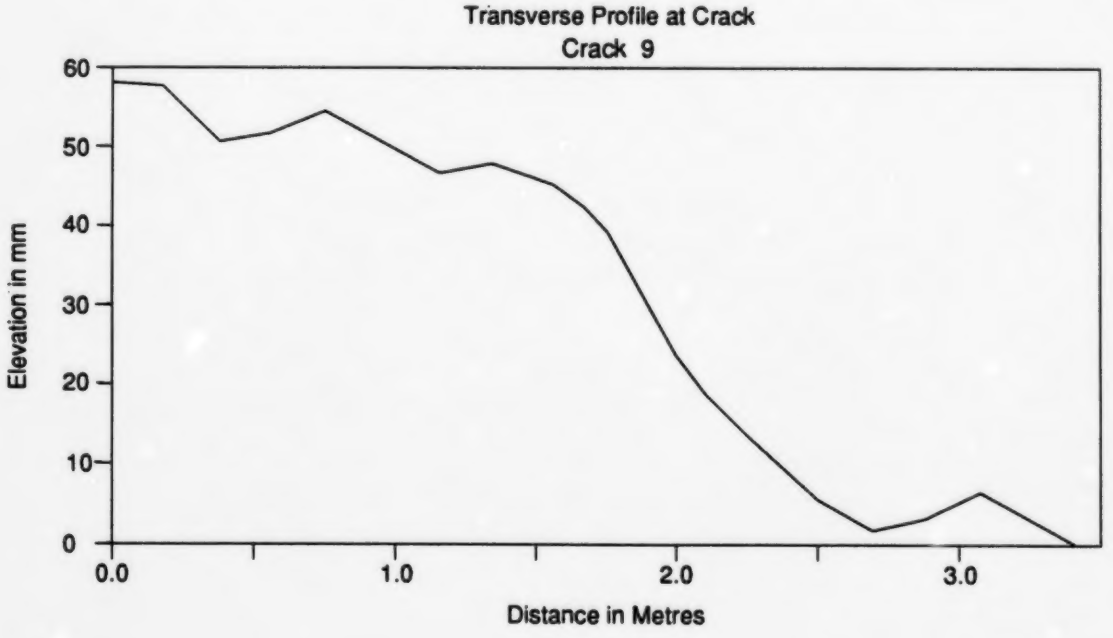


Figure 4/ Profiles of Test Crack No. 9 (Rating: Very Severe)

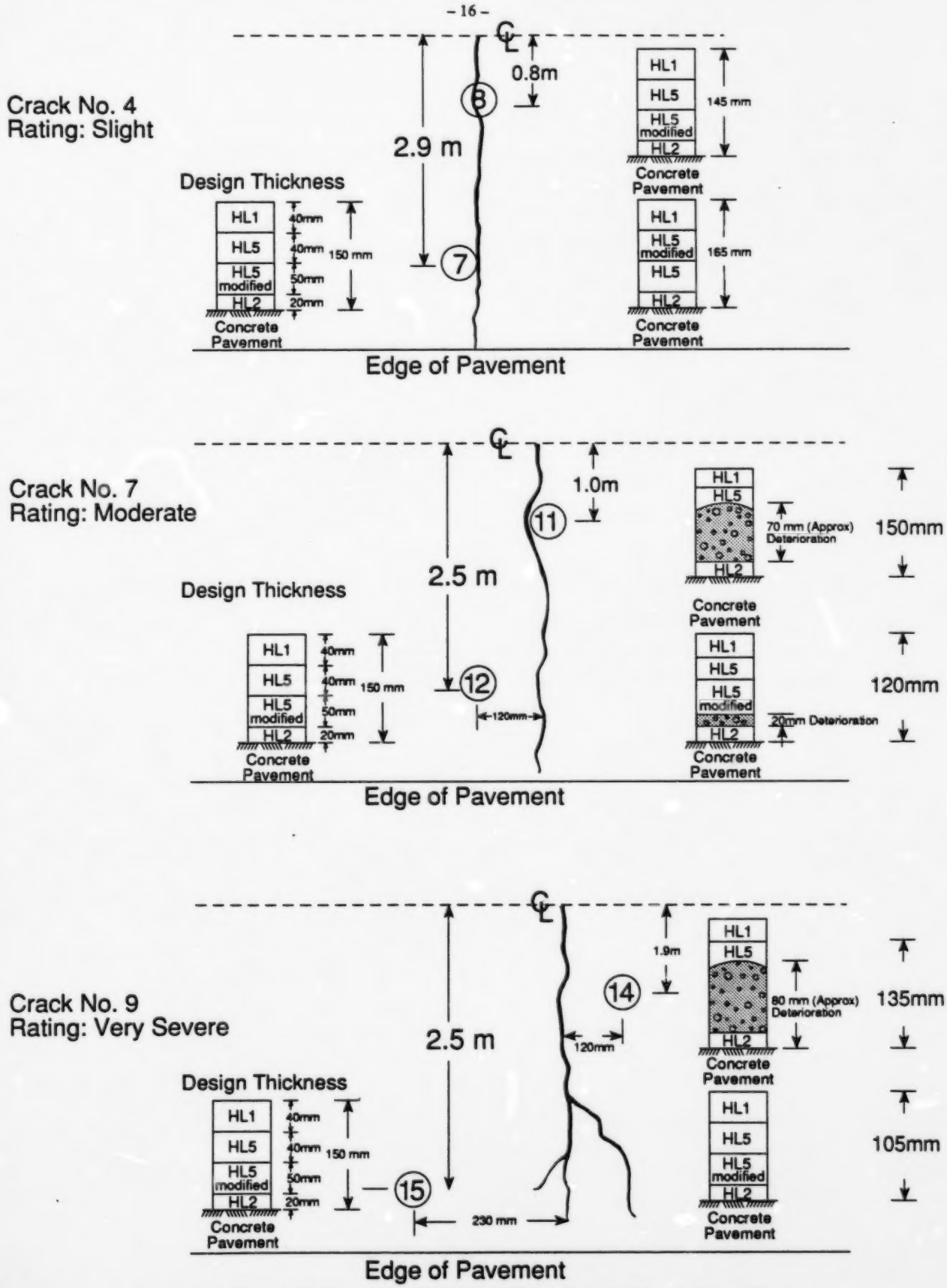


Figure 5/ Core Investigation 0f Test Cracks No. 4, 7 and 9

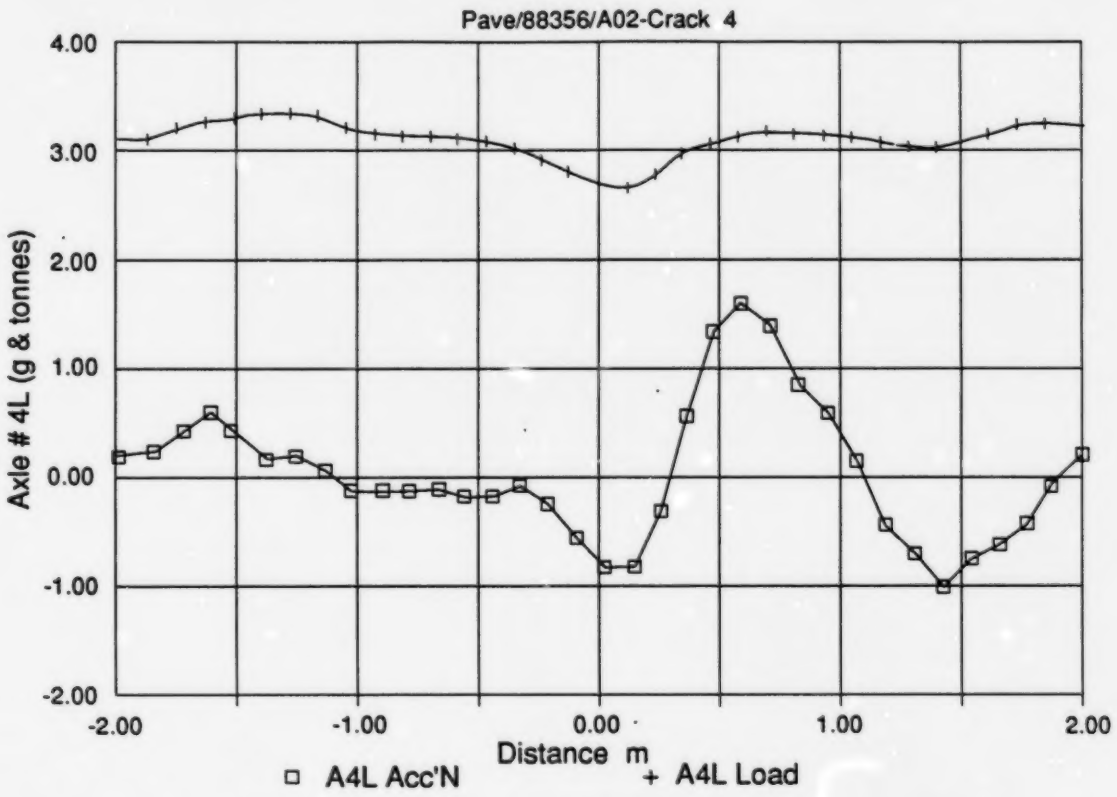


Figure 6/ Crack Study, 401 W/B, Belle River to Puce Rd

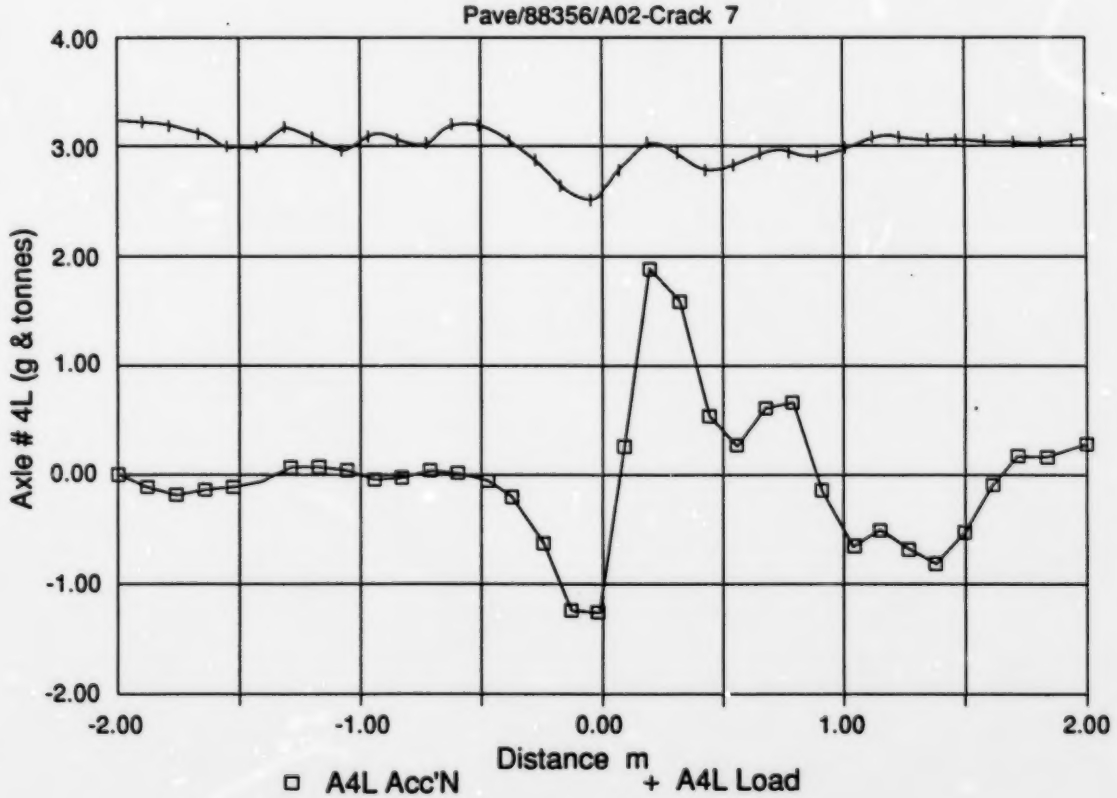


Figure 7/ Crack Study, 401 W/B, Belle River to Puce Rd

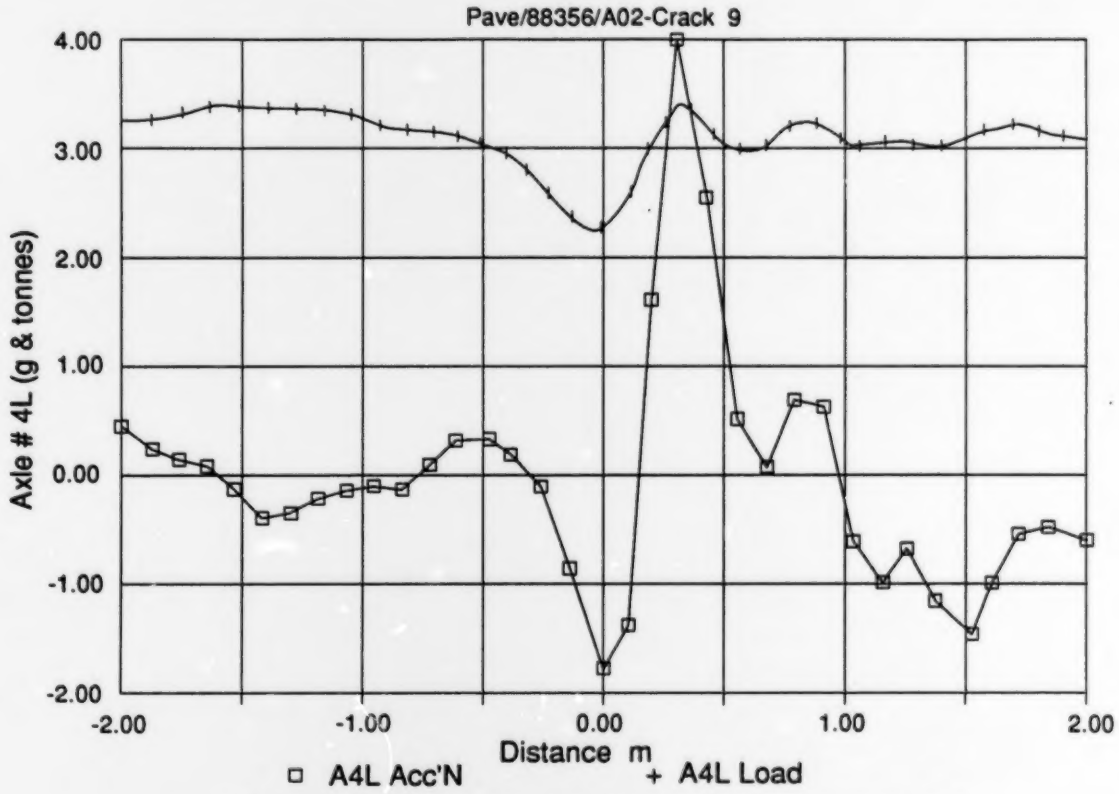


Figure 8/ Crack Study, 401 W/B, Belle River to Puce Rd

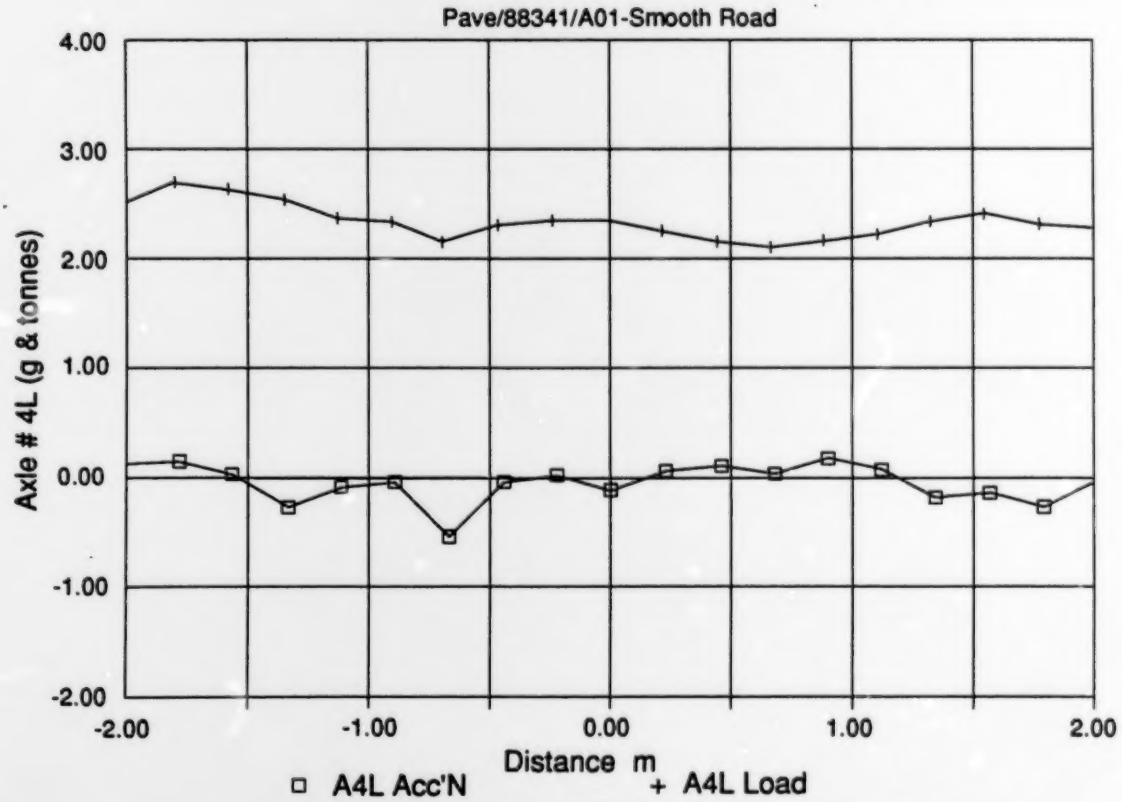


Figure 9/ Crack Study, Highway # 73 S/B, South of 401